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POLICY BRIEF

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Exploring the 'solution space' is key: SOLUTIONS recommends an early-stage assessment of options to protect and restore water quality against chemical pollution

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Abstract

Present evaluations of chemical pollution in European surface and groundwater bodies focus on problem description and chemical classification of water quality. Surprisingly, relatively low attention has been paid to solutions of chemical pollution problems when those are encountered. Based on evaluations of current practices and available approaches, we suggest that water quality protection, monitoring, assessment and management of chemical pollution can be improved by implementing an early-stage exploration of the 'solution space'. This follows from the innovative paradigm of solution-focused risk assessment, which was developed to improve the utility of risk assessments. The 'solution space' is defined as the set of potential activities that can be considered to protect or restore the water quality against hazards posed by chemical pollution. When using the paradigm, upfront exploration of solution options and selecting options that would be feasible given the local pollution context would result in comparative risk assessment outcomes. The comparative outcomes are useful for selecting optimal measures against chemical pollution for management prioritization and planning. It is recommended to apply the solution-focused risk assessment paradigm to improve the chemical pollution information for river basin management planning. To operationalize this, the present paper describes a still-growing database and strategy to find and select technical abatement and/or non-technical solution options for chemical pollution of surface waters. The solutions database and strategy can be applied to help prevent and reduce water quality problems. Various case studies show that implementing these can be effective, and how solution scenarios can be evaluated for their efficacy by comparative exposure and effect assessment.

Challenge

Water quality protection, monitoring, assessment and management is a key challenge, especially for chemical pollution [1–4]. Chemical pollution of surface water systems encompasses a group of distinct problems, characterized by highly diverse mixture compositions and associated high diversity of exposures and probable impacts [5, 6], in a context of widely varying

non-chemical stressors and local natural conditions [7]. Consequently, there is a high diversity of protection and impact-driven restoration needs, which are the two key environmental objectives of the European Water Framework Directive (Article 4, WFD [1]). Water quality protection and assessment requires an improved coverage of this diversity to understand the water quality problems [6, 8–11] and also approaches to derive and select management solutions for those problems. This holds especially in view of the benefits of a non-toxic environment [12].

The EU-project SOLUTIONS (www.solutions-project.eu) aimed to address these problems. Due to the

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diversity of the mixture exposure, the idea of a ‘one-size-fits-all’ approach for protection and restoration is unlikely to be effective. To improve on the current situation, the project adopted a relatively novel risk assessment paradigm, solution-focused risk assessment [13]. This paradigm was proposed by the U.S. National Academy of Sciences after a wide-ranging evaluation of risk assessment practices of the U.S. EPA to improve the utility of risk assessments by an early-stage attention on the exploration of the ‘solution space’ for the environmental problem at hand. The ‘solution space’ is defined as the set of potential activities that can be considered to protect or restore the water quality against hazards posed by chemical pollution. The ‘solution space’ is wide. It not only concerns the option to implement a technical abatement option on a specific site as a reactive solution (e.g., an improved wastewater treatment installation), but also the strategic development and implementation of sustainable chemistry as a proactive solution [14]. A systematic database to store and retrieve options in the ‘solution space’ is lacking, but would be beneficial to water quality managers.

The solution-focused approach itself is not new, and its power has been established a long time ago. An early example is the successful reduction of the spread of cholera in nineteenth century London, by removing the handle of a drinking water pump [15]. The identified problem was thus an infectious disease, which was at that time thought to be spread via air. Data on the spread of the disease were collected and evaluated on a system-level basis (the disease incidences in a London neighborhood). By considering available information and solution opportunities, the implemented solution was a simple removal of the water pump handle. The WFD (Annex II) also stipulates that water quality managers collect available evidence on a water system-level basis (multiple lines of evidence), to establish the likelihood of stress factors to cause (potential) impacts and to subsequently derive effective programs of measures.

The current WFD-assessment and management cycle has been extensively described in guidances, be it that in the written texts and current practices the emphasis is on problem description and on water quality classification [16]. There is far less attention to the systematic translation of problems into management solutions (for protection or restoration).

The current assessment and management cycle follows the so-called DPSIR causal framework [8, 17]. This implies that water management practices consider the drivers of water quality reduction (D, e.g., economic activities), the resulting pressure (P, e.g., emissions of chemicals to the water system), the subsequent status of the water quality (S, e.g., the concentrations of

compounds) and the resulting impacts (I, e.g., species abundance changes). Combining the information on D, P, S and I should yield the management response (R). The DPSIR approach explicitly suggests that the response R may consider potential solutions (the *Responses*, R) in the format of reductions of D, P, S and I. Water quality assessors are suggested to combine various lines of evidence (WFD-Annex II) to establish the *need* for water quality protection or restoration. It is a lost opportunity for water quality management not to support this step by organizing the systematic storage and retrieval of optional elements in the ‘solution space’, that is: the ‘*what can be done?*’ question. As shown below, the solution-focused paradigm can be aligned with the DPSIR cycle.

The provision of a database and strategy for exploring the ‘solution space’—and optionally the experiences of others with specific solutions—would serve water quality management practices. The inclusion of a ‘preference ladder’ into such a system would further improve its usefulness.

Thus, the fundamental challenge of water quality management is to improve the utility of the solution-focused risk assessment paradigm, by providing a strategy for and information on the available options in the ‘solution space’, so that practitioners can select practicable options for their specific water quality problems. This challenge was addressed by improving the applicability of the solution-focused risk assessment approach for the problem of chemical pollution and by describing several case studies that show how that serves European water quality management. This was achieved utilizing the conceptual framework [18, 19] and adding new elements to it:

1. a database for technical abatement options and non-technical solution options,
2. a strategy to use the solution-focused approach in practice and
3. chemical footprints (to enable evaluation of trends in chemical pollution threats and to predict approaches to handle future emerging pollutants).

Recommendations

- Implement the innovative paradigm of solution-focused risk assessment [13] to water quality protection, assessment and management of European surface waters, in line with employing the DPSIR causal framework at all spatial scales (EU-wide, basin-specific and local water bodies).
- Pay early attention to the exploration of the ‘solution space’ that is available to *Respond* (the “R” in DPSIR) to chemical pollution threats.

- Collate technical abatement and non-technical solution strategies in a database and a strategy, to assist practitioners in identifying and selecting potential (cost-)effective options for preventing or solving chemical pollution problems.
- Combine the information on the 'solution space' with lines of evidence collated via the DPSIR approach and (cost-)effectivity to identify the optimum strategy.
- Apply sensitive indicators of chemical pollution (chemical screening, improved concentration-based and effect-based methods) to enable the evaluation of improvements in water quality (lowered chemical pollution stress and/or increased ecological status).
- Evaluate solution scenarios using all available lines of evidence, which not necessarily requires complete data on all aspects of pollution. This can be done *ex ante* to select the best options, and *ex post* to evaluate water quality improvement of an implemented management action.
- Employ rigorous operational monitoring to demonstrate that a solution scenario has been effective, and where extra efforts are needed
- Use comprehensive metrics, such as chemical footprints, to describe trends in water quality improvements following or expected from implementing a solution scenario. Chemical footprints can be used to evaluate options to evaluate strategies to handle future emerging pollutants.
- incentives to operationalize the solution-focused risk assessment process by providing suitable guidance. This can be achieved either by adapting existing guidance documents from the series of *Common Implementation Strategy* documents (e.g., [16, 17]), or by providing novel documents; it will also be essential to provide tools for storage and retrieval of solution-oriented options and experiences;
- preventive evaluations of future emerging compounds, by modeling future chemical pressures resulting from actual and predictable developments in society;
- recognition that water quality assessors commonly combine multiple lines of evidence to establish the likelihood that chemical pollution affects water quality and to subsequently derive programs of measures;
- the active use, evaluation and further improvement of the solution-focused risk assessment approach.

Requirements

Developing effective solutions to water management challenges regarding the problem of chemical pollution requires:

- recognition that current risk assessments have limited utility, as they are often mainly problem oriented rather than solution focused, and are qualitative (binary classification of chemical pollutants) rather than quantitative (continuous ranking of chemical pollution severity);
- agreement that solution-focused risk assessment implies an improved utility of its outcomes for the derivation of management plans, due to an orientation to exploring the 'solution space' early on (provided that the problem remains to be comprehensively described);
- development and implementation of a sensitive indicator system for chemical pollution that shows water quality improvements that result from a set of measures taken, given that the current 'one-out-all-out' principle keeps positive trends invisible until the final goal is reached;

Achievements

1. The DPSIR causal approach, the conceptual framework and the response issue

The WFD [1] is based on a water systems-level approach, recognizing that water systems are natural systems of river basins that commonly cross multiple national borders and jurisdictions. Water systems may be threatened by the mixtures of chemicals ('specific pollutants') that are emitted in significant amounts to the water system. Those result in a highly diverse chemical pollution pattern at the site of emission and/or downstream [6, 9].

To handle this vast diversity of pollution situations, we suggest that water quality assessors employ a systematic approach to diagnose water quality problems and their probable causes, as prescribed in the WFD-Annex II. We therefore combined the WFD-suggested DPSIR approach [8, 16]) with the extended conceptual framework for solution-focused management of chemical pollution in European waters [13, 19]. The result of the combined concepts is shown in Fig. 1. The present paper focuses specifically on early-stage attention for exploring optional *Responses* (R), that is, to explore the 'solution space' when a water quality problem is hypothesized or found. The WFD (Annex VI) does provide already a list of standard measures that can be addressed as potential solutions to be considered for the programs of measures (Additional file 1). The list suggests that the 'solution space' is large, but it does not provide a very specific or operational strategy or solution approaches. Figure 1 suggest that the 'solution space' encompasses technical abatement options (lower left, 'Abatement'), but also suggests how to explore the 'solution space' further (via

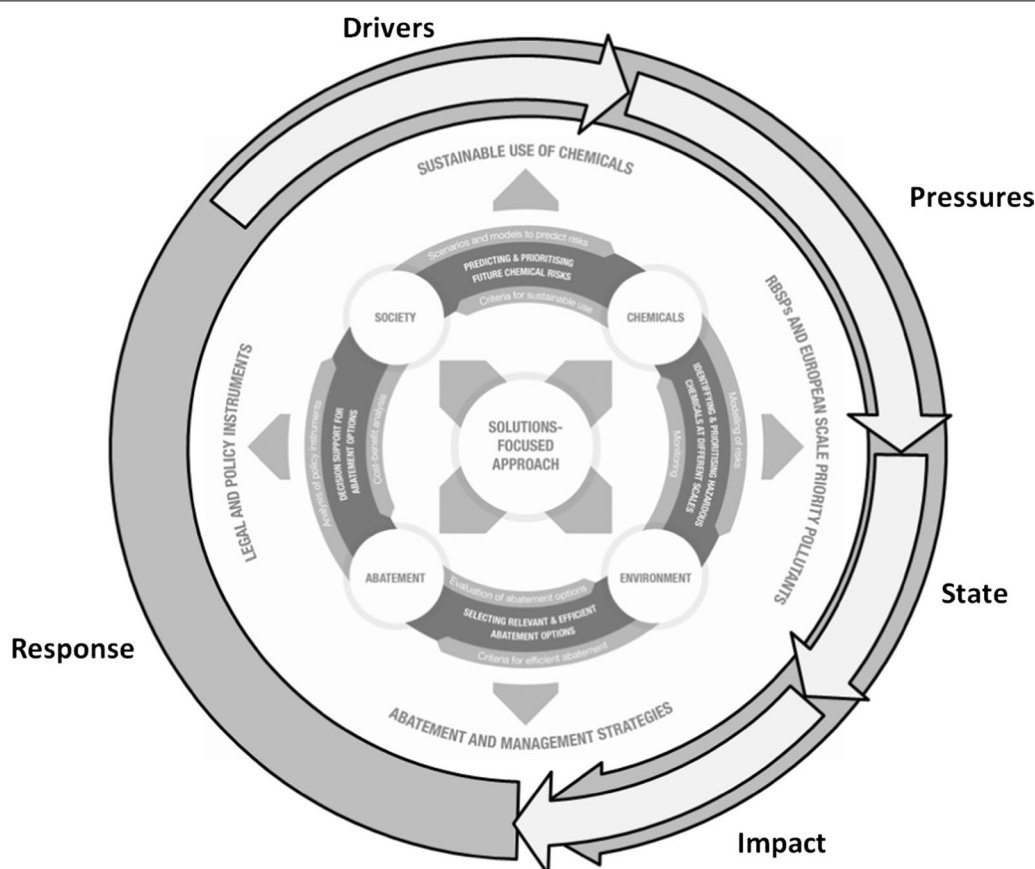


Fig. 1 The solution-focused risk assessment paradigm as proposed by the U.S. National Academy of Sciences [13] was operationalized for the assessment and management of chemical pollution of surface waters [19]. This supports practitioners in considering the 'solution space' for preventing or reducing chemical pollution (including technical abatement options), which can be valued as potential *Response* to pollution

the entries 'Chemicals', 'Environment' and 'Society'), as detailed below.

Given the conceptual framework of Fig. 1 and the tools and services to characterize water quality problems [20], we aimed to systematically collate abatement techniques and management options and strategies and to make the results available for re-use by others encountering a similar chemical pollution problem. Systematic storage of those—with or without evaluating them—enables a whole community of users to retrieve collated options and experiences, and thus to explore a wide array of options. Users can retrieve options in the 'solution space', to derive programs of measures for their specific problem (see below).

As compared to current practices, the combined framework (Fig. 1) encompasses a change from single chemicals per site to a system-level approach, from a problem description-oriented approach to (also) a solution-targeted approach, and from a limited view on the 'solution space' to a systematic basis to recognize that the 'solution space' is large.

2. The early exploration of the 'solution space'

The early management attention to the *Response*-step (R) of the DPSIR causal cycle can be supported by systematic collations of data on technical abatement options and a description of the management strategy. To that end, such information was collated in a database of technical abatement options [21], and in a proposal for the systematic evaluation of non-technical solution scenarios (see Additional file 1). Both were designed to be broadly applicable. This supports users in exploring the 'solution space' and may help to inspire them to evaluate options they would never have thought of, and the availability of a database of options helps to avoid that 'the wheel is re-invented over and over again'.

The *technical options* are provided as a database of technical abatement options and efficiencies for the application in wastewater and drinking water treatment plant construction and upgrading [21]. The database provides insights into the degree of expected removal of hazardous chemicals from wastewater and raw water for drinking water production for various techniques. This

was achieved by an analysis of the installation-specific removal efficiencies of chemicals with different physical–chemical properties. It should be acknowledged that the database can be continuously expanded, based on the experiences gained, which would further improve the value of the technical abatement database.

The *non-technical options* were found to be highly diverse (Fig. 2). The exploration of prevention and management strategies is currently formatted as a strategy to explore the ‘solution space’ (Fig. 2). Note that this figure is directly derived from and related to the conceptual framework (Fig. 1). It provides a generic scheme that supports end users in exploring the non-technical ‘solution space’. The visualization of the ‘solution space’ in Fig. 2 shows that there are three general levels to approach a pollution problem, going from operational via tactical to strategic options. Note that the discrimination between these levels is not strict. Further details are in Additional file 1. Figure 2 shows how the conceptual framework (Chemicals, Environment, Abatement and Society, Fig. 1) thus in general supports a systematic exploration of the available ‘solution space’ (Fig. 2).

The application of the strategy and the scheme of Fig. 2 are further elaborated in Additional file 1. There are two final remarks on the ‘solution space’ in relation to other

(non-chemical pollution) stress. First, it should be noted that the exploration of the ‘solution space’ in the present paper focused on chemical pollution only. However, the diagnosis of impacts of all stressors may show that chemical pollution is only part of the problem, or even negligible, and that the ‘solution space’ for the integrated management plan should also consider the solutions to other stressors. Second, it should be noted that a single solution strategy may help reduce the impacts of multiple sources of stress. For example, zonation (between land use and water systems) helps reduce emissions of both nutrients and agricultural chemicals.

3. Prioritizing the intensity of measures against chemical pollution

Diagnostic results—ranking sites and compounds regarding the relative importance of chemical pollution to cause harm—are needed as a first step to help prioritize the need for and intensity of the measures that can be taken to prevent or reduce chemical pollution problems. As any compound (currently in trade, or produced in the future) can pose harm (alone or in a mixture), the WFD and current research therefore consider all compounds and their mixtures. The diagnostic step is supported by diagnostic tools and services

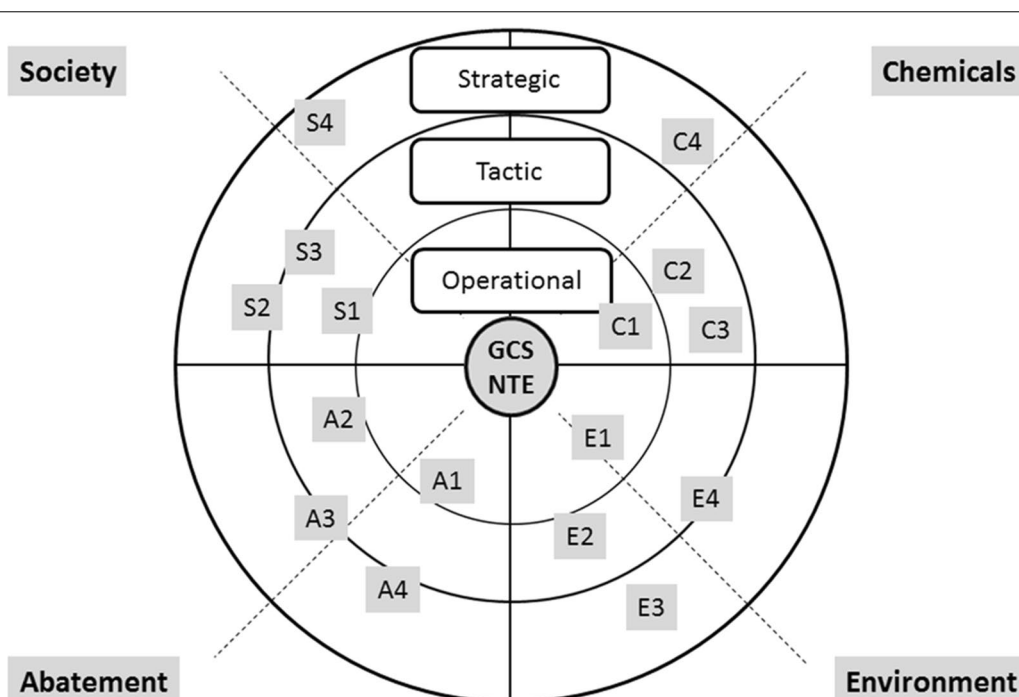


Fig. 2 The strategy for exploring the ‘solution space’, based on the conceptual framework (Fig. 1, [19]). The different codes (C1, C2, ...etc.) visualize that there are widely different options in the ‘solution space’, ranging from operational options for local application (e.g., to swiftly solve a local water quality problem), up till tactical and strategic options for (inter)national water governance. The diversity of codes is explained in the text, and some examples are summarized in Additional file 1

(e.g., [6, 10, 11]) and helps to steer management efforts to those sites and compounds that are most problematic for reaching the WFD environmental goals (good chemical and ecological status). The exploration of the 'solution space' might focus on prioritized water bodies and compounds, but would also consider lower-ranked cases where a solution option is relatively easy to implement.

4. Solution-focused practices

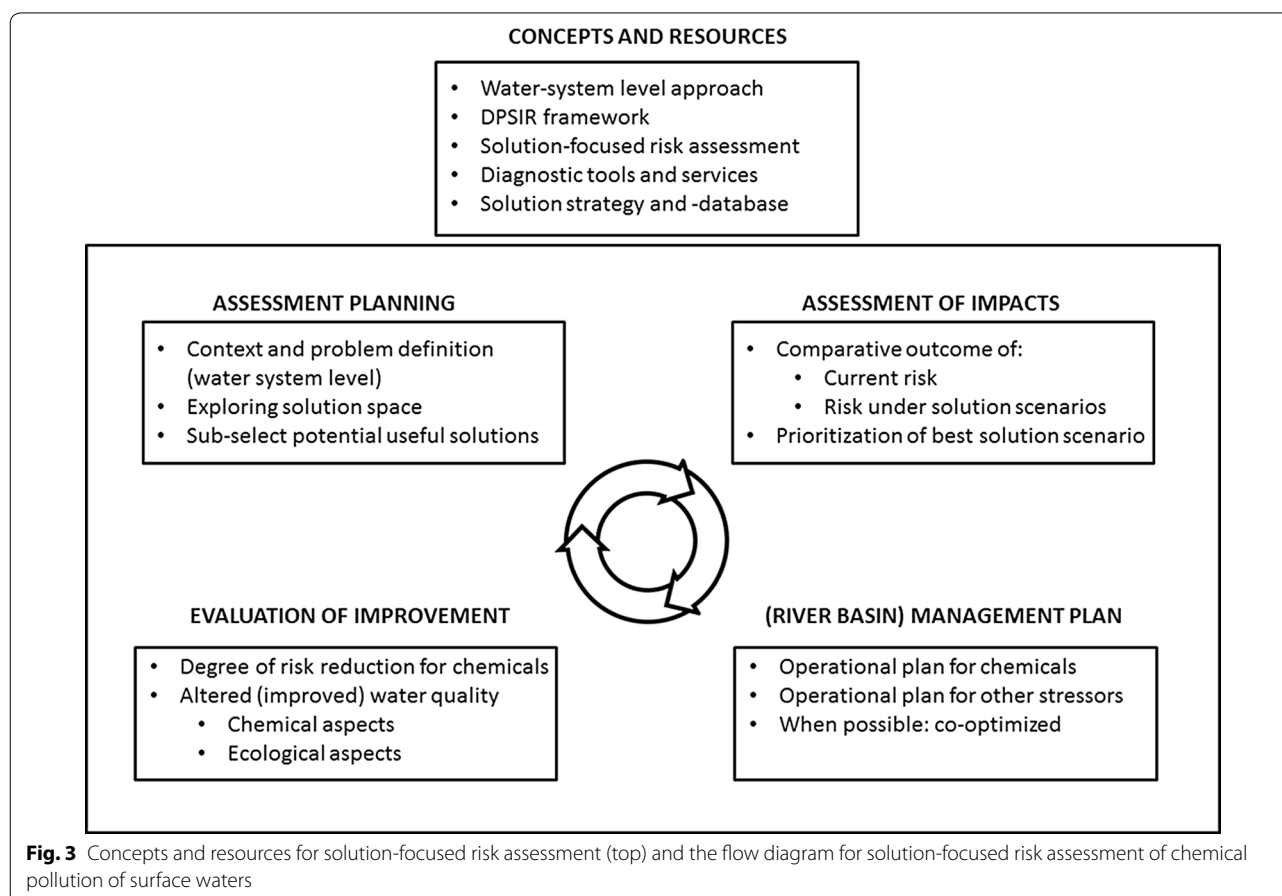
So far, the recommended approaches are introduced as novel concepts, with generic schemes to assist water quality assessors in practice. The combination of the solution-focused framework, the diagnostic approaches and the database and strategy for exploring the 'solution space' yields a novel flow diagram (Fig. 3). The diagram closely relates to the current WFD-assessment and management cycle, but emphasizes the novel key step (early focus on exploring the 'solution space') as well as the aforementioned recommendations to improve current practices (such as to follow the systems-level approach of the WFD).

5. Evidence for improved status

Case studies have shown that the implementation of solution strategies resulted in reduced chemical pollution problems in European surface water systems.

First, the chemical, bioanalytical and ecological tools that are available were used to evaluate chemical pollution in relation to the efficacy of wastewater treatment plants (WWTPs) in removal of chemicals and reducing risks and impacts [22, 23]. The evaluation considered WWTP upgrades with an added activated carbon treatment step and considered up- and downstream and before/after comparisons. It was demonstrated that the improved treatment influenced ecosystem exposure (reduced) and quality (improved). The extra carbon treatment was beneficial for the chemical, biological and ecological status of the receiving water bodies [22–25].

Second, additional studies considered ten riverbank filtration sites along the River Rhine and its tributaries, and looked at modeling, existing data and additional analytical measurements of trace organic compounds to assess the attenuation potential of selected chemicals present in the surface water by riverbank filtration. For a site with long retention times to the drinking



water well, the results enabled the categorization into very persistent, partially removable and fully removable compounds in the given time scales [26]. For three sites with short travel times, a broad analytical screening enabled categorization of the chemicals into “persistent” and “naturally attenuated” classes [27]. For one Dutch site, the efficiency of anaerobic riverbank filtration was assessed before and after reverse osmosis treatment, using a battery of bioassays combined with non-target screening. The treatment process of reverse osmosis was characterized in more detail using spiked anaerobic riverbank filtrate [28].

Monitoring can also directly trigger a solution strategy or method. Daily wide-scope target and non-target screening of water samples using high-resolution mass spectrometry at River Rhine stations triggered successful abatement measures when non-regulated and non-monitored relevant chemicals were detected [29]. Many pollution sources can be located in river catchments via DPSIR analyses and/or monitoring. The example case studies cited above, as well as scenario studies with models [6], show that corrective measures, such as change in industrial production processes or improved waste management, can significantly reduce or eliminate discharges and chemical pollution risks.

6. Exploring future options

The compilation of optional technical abatement and management strategies can be followed by a ‘fitness check’ of expected water quality improvements. Here, the water quality assessor evaluates each option with respect to critical aspects, such as practical implementation, costs and efficacy. Scenario analyses can be run to evaluate the expected improvements in water quality, applying component-based approaches. An example result of such a comparative assessment is shown in a case study of future emission scenarios of chemicals at the European scale under alternative policy strategies [6, 30]. The most remarkable result was a highly positive effect (35% less toxic pressure, expressed as multi-substance potentially affected fraction, msPAF) of the phasing out of 26 substances of very high concern (SVHC) listed on the REACH Candidate List (out of the 1357 chemicals registered under REACH that were included in the ‘future management’ scenario). This clearly shows the high potential of focused regulatory measures to reduce the total chemical burden in general [31]. But specifically, the water quality change in relation to SVHC-focused emission reduction measures appeared to be more than proportional, driven by non-linear exposure–effect relationships (see also [32, 33]).

7. Evaluation and communication of trends: chemical footprints

Communicating the output of the changes following from an implemented solution scenario and/or future management scenarios requires an innovative approach for evaluating trends and communicating results. This is key, given the diverse appearances of the chemical pollution problem. A chemical footprint approach was developed for this, providing summary information of the chemical pollution for an area [34, 35]. The chemical footprint indicator provides summary insights in the net likelihood of chemical pollution to cause harm. Indications for a decreasing chemical footprint were found in a retrospective study of a European basin [35], in line with emission reduction policy objectives and efforts and associated observations made with effect-based methods. The chemical footprint indicator can currently provide insights in the chemical footprint at the level of local water bodies. That is, the management-relevant outcomes of current chemical footprint analysis consist of (1) information whether and in how far upstream ‘source’ areas contribute to a local mixture risk, (2) information on the relative importance of chemical emissions to the local mixture toxicity and (3) information on whether and in how far mixture toxicity from a polluted water body is transported to downstream ‘target’ areas [36]. These types of information are key to define programs of measures against pollution and which actors to address (upstream or local) who have shared responsibility in causing risks (1 and 2) and to inform water managers of the downstream areas.

8. Further developments

The success of water quality protection and management regarding chemical pollution depends on the possibility to identify and implement optimal abatement techniques and management approaches [31, 37]. The implementation of the solution-focused risk assessment paradigm into the practice of European water management is supported by a conceptual framework that guides the assessment process and provides a systematic overview of available abatement and management strategies. The abatement database and the management strategies are continuously expanding, following the continued cycle of water quality management activities and monitoring-based water quality evaluations.

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s12302-019-0253-6>.

Additional file 1. Strategy to explore the 'solution space' to protect and restore water quality in relation to chemical pollution.

Abbreviations

DPSIR: Drivers, Pressure, Status, Impact and Response; msPAF: multi-substance potentially affected fraction; REACH: registration, evaluation, authorization and restriction of chemicals; SVHC: substances of very high concern; WFD: Water Framework Directive; WWTP: wastewater treatment plant.

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Authors' contributions

LP and AvW conceptualized and drafted the manuscript. All other authors helped to further elaborate the manuscript and contributed specific aspects. All authors read and approved the final manuscript.

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